ESTIMATION OF THE NUMBER OF PROMPT FISSION GAMMA RAYS

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The correlation between the total prompt gamma ray energy from fission and the number of prompt neutrons emitted from fission is used to estimate the average number of prompt gamma rays from fission in lieu of performing a measurement. Competition in the emission of prompt gamma rays and neutrons from the de-excitation of fission fragments has been observed experimentally. Nifenecker et al.[1] demonstrated that a linear relationship exists between the total prompt gamma ray energy, E_t, from fission and the number of prompt neutrons, ν, from the spontaneous fission of ^{252}Cf:

$$E_t(\nu) = 0.75\nu + 4.0. \tag{1}$$

The constant term is the average residual excitation energy of the fission fragments after neutron emission without considering correlation in the emission of prompt neutrons and gamma rays. This constant was assumed to be the same for all fission processes. Sufficient experimental data exist to determine if the relationship in Eq. 1 is applicable for all fission processes. Hence, a more general extension of Eq. 1 would relate the total prompt gamma ray energy, $E_t(\nu,Z,A,)$, to the pre-fission mass (A), the atomic number (Z), and the number of prompt neutrons (ν) from fission via

$$E_t(\nu, Z, A) = \varphi(Z, A)\nu + 4.0. \tag{2}$$

The function $\varphi(Z,A)$ is an arbitrary function determined by trial and error to provide the most linear relationship between the estimated values of E_t and the average measured values for ^{235}U, ^{239}Pu, and ^{252}Cf. The function $\varphi(Z,A)$ varies linearly with $Z^2A^{1/2}$

$$\varphi(\mathrm{Z,A}) = 2.51(\pm 0.01) - 1.13 \cdot 10^{-5}(\pm 7.2 \cdot 10^{-8})Z^2\sqrt{A}. \tag{3}$$

No physical significance has yet been attributed to the functional form of $\varphi(Z,A)$. The estimated total prompt gamma ray energy for thermal neutron induced fission of ^{233}U

calculated using Eqs. 2 and 3 is 6.61 ± 0.03 MeV assuming 2.494 ± 0.006 prompt neutrons from ^{233}U thermal neutron fission as measured by Gwin et al.[2] This value is in close agreement with the measured value of the total prompt gamma ray energy from the thermal neutron induced fission of ^{233}U (6.69 ± 0.3 MeV) obtained by Pleasonton.[3] This example demonstrates that the total prompt gamma ray energy for spontaneous fission or thermal neutron induced fission can be adequately estimated using Eq. 2.

A linear fit of the measured average energy, $<E>$, of prompt fission gamma rays from ^{235}U, ^{239}Pu, and ^{252}Cf produces the following relationship between the average prompt gamma ray energy, the atomic number (Z), and the pre-fission atomic mass (A)

$$< E > = -1.08(\pm 0.004) + 106.9(\pm 0.2) Z^{1/3} / A. \qquad (4)$$

The estimated average prompt gamma ray energy for thermal neutron induced fission of ^{233}U is 0.99 ± 0.01 MeV using this expression. This value essentially agrees with Pleasonton's measured value of 1.06 ± 0.07.

The average number of gamma rays from fission is approximated as

$$< G > = \frac{E_t(\bar{v}, Z, A)}{< E >}. \qquad \textbf{(5)}$$

The expression for $E_t(v,Z,A,)$ is provided in Eq. 2 and is evaluated using $\bar{v}$ for the fission nuclide. The expression for $<E>$ is given in Eq. 4. Application of Eq. 5 for thermal-neutron-induced fission of ^{233}U yields a value of 6.69 ± 0.05 which agrees fairly well with the measured value of 6.31 ± 0.3 by Pleasonton. The difference between the estimated average number of prompt gamma rays from fission and Pleasonton's measured value for ^{233}U results because the estimated value of the average energy of prompt fission gamma rays from ^{233}U thermal neutron induced fission is underestimated

compared to Pleasonton's measured value. These models were used to estimate the properties of prompt gamma rays from the spontaneous fission of various nuclides that are encountered in nuclear safeguard applications. The estimated prompt gamma ray parameters for spontaneous fission of ^{238}U, ^{238}Pu, ^{240}Pu, ^{242}Pu, ^{242}Cm, and ^{244}Cm are presented in Table 1. The total prompt gamma ray energy was estimated using the average number of neutrons from fission for each nuclide in Eq. 2. The average energy of prompt gamma rays from fission was estimated using Eq. 4, and the average number of prompt gamma rays from fission was estimated using Eq. 5.

The data presented in Table 1 can be used to characterize spontaneous fission isotopes commonly encountered in nuclear safeguard applications. This information may prove useful for development of advanced nondestructive assay methods. Furthermore, the models presented in this summary provide a mechanism to estimate gamma ray properties for any fission process. The use of models to estimate gamma ray properties from fission highlights the fact that little experimental data exists for many spontaneous fission nuclides. Measurements of the gamma ray properties would not only be useful for developing nondestructive assay methods but would also provide additional information about the fission process.

REFERENCES

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Table 1. Estimated properties of gamma rays from spontaneous fission of ^{238}U, ^{238}Pu, ^{240}Pu, ^{242}Pu, ^{242}Cm, and ^{244}Cm using Eqs. 2, 4, and 5

Isotope	Total energy (MeV)	Average number	Average energy (MeV)
^{238}U	6.06 ± 0.03	6.36 ± 0.05	0.95 ± 0.01
^{238}Pu	6.14 ± 0.03	6.35 ± 0.05	0.97 ± 0.01
^{240}Pu	6.07 ± 0.03	6.39 ± 0.05	0.95 ± 0.01
^{242}Pu	6.05 ± 0.03	6.49 ± 0.05	0.93 ± 0.01
^{242}Cm	6.26 ± 0.04	6.60 ± 0.05	0.95 ± 0.01
^{244}Cm	6.40 ± 0.04	6.88 ± 0.06	0.93 ± 0.01